DROOP COMPENSATED PULSE FORMING NETWORK DRIVEN PULSED TRANSFORMER DESIGN*

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ABSTRACT

Pulse transformers are often used in pulsed power for high voltage generation. Unfortunately, due to their transfer characteristics, transformers degrade the input pulse (i.e. limit the risetime, droop exponentially, etc). For low impedance (less than a few tens of Ohms) and long output pulse (on the order of a few microseconds) applications, it is extremely difficult, if not impossible, to use pulse transformers. We describe in this paper pulse forming networks (PFNs) which are droop compensated to make the output pulse square for the duration of the input pulse. Using this technique, one can design a PFN which can deliver constant power to a wide range of loads (with the proper transformer load combinations) [1].

THEORY

The authors have shown in an earlier paper [2] that in order to obtain a flat output pulse from a transformer, the necessary primary current should be as shown in Figure 1, and is expressed as

$$i_1(t) = [(L_2/M)I_2 + (R/M)I_2 t]u(t) \qquad (1)$$

where:

- $i_1(t)$ -- transformer primary current
- I_2 -- magnitude of the secondary current
- L_1 -- primary self inductance
- L_2 -- secondary self inductance
- M -- mutual induntance = $k*(L_1L_2)^{1/2}$
- R -- load resistance
- $u(t)$ -- unit step function

By the usual Fourier transform and network theory, the necessary PFN values can then be expressed mathematically as [2,3,4,5,6]

$$L_{odd} = \frac{1}{4+2(RT/L_2)} \qquad (2a)$$

$$C_{odd} = \frac{4+2(RT/L_2)}{n^2\pi^2} \text{ (charged)} \qquad (2b)$$

$$L_{even} = \frac{1}{(2RT/L_2)} \qquad (2c)$$

$$C_{even} = \frac{(2RT/L_2)}{n^2\pi^2} \text{ (uncharged)} \qquad (2d)$$

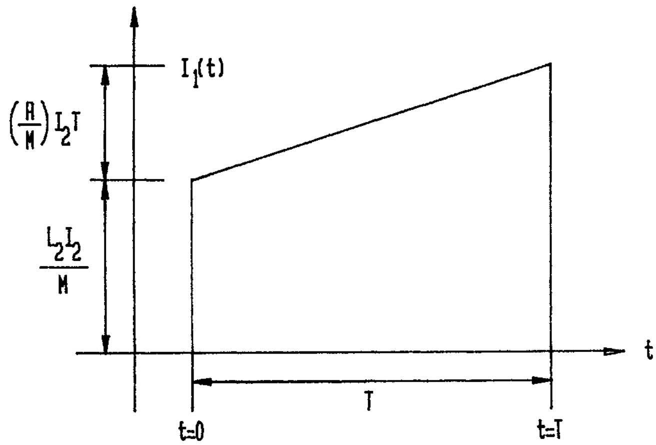

Figure 1. Required Transformer Input

where

- T -- pulse duration
- n -- integer representing the harmonics

Such a PFN is shown schematically in Figure 2. It was also shown that unlike normal PFNs, the DCPFNs can be made to deliver constant power pulses to a wide range of loads provided that the dimensionless droop parameter term, $2RT/L_2$, remained the same (i.e. matched by the transformer-load combinations). The direct consequence of which is that DCPFNs can be made into <u>Constant Power Sources</u> with the proper transformer load combinations.

DESIGN

For each typical PFN, load impedance (Z) and pulse duration (τ) are specified. However, an added scaling parameter is necessary for the DCPFN. This is the secondary self inductance of the transformer.

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Pulse transformers are often used in pulsed power for high voltage generation. Unfortunately, due to their transfer characteristics, transformers degrade the input pulse (i.e. limit the risetime, droop exponentially, etc). For low impedance (less than a few tens of Ohms) and long output pulse (on the order of a few microseconds) applications, it is extremely difficult, if not impossible, to use pulse transformers. We describe in this paper pulse forming networks (PFNs) which are droop compensated to make the output pulse square for the duration of the input pulse. Using this technique, one can design a PFN which can deliver constant power to a wide range of loads (with the proper transformer load combinations) [1].

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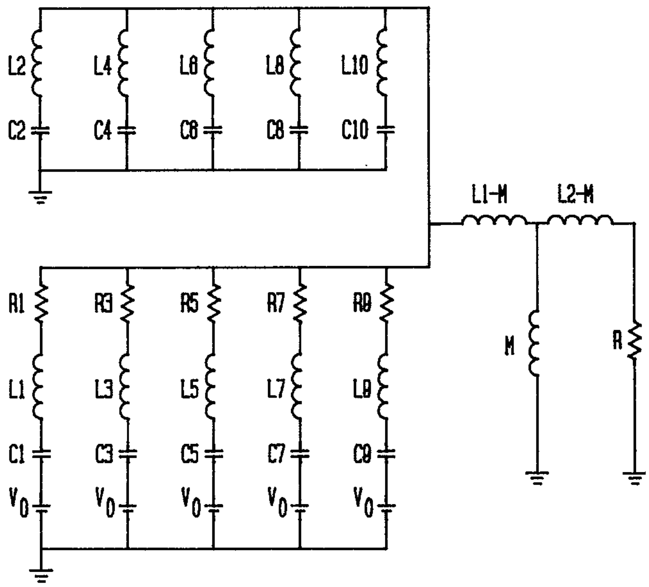

Figure 2. DCPFN Driven Pulsed Transformer

Example of the DCPFN

Suppose it is desirable to generate 100GW pulses for 2.5μs, with loads ranging from 1.6 Ohms to 10 Ohms. It is possible to do so by having the proper pulse transformer, described in Table 1, or any of the transformer load combinations tabulated in Table 2 [1,2] which utilize the DCPFN values of Table 3. The simulated output for the case of the 10 Ohm load (1MV, 100GW) is shown in Figure 3 [7]. As described earlier, this 100GW pulse can be delivered to any of the transformer load combinations of Table 2.

Efficiency Considerations

A price is paid for the versatility of DCPFNs however, since the DCPFN efficiency

$$\eta = \frac{4}{4+2(RT/L_2)} * 100\%, \qquad (3)$$

is decreased by the droop parameter term. Normalized coefficients of the DCPFN for efficiencies ranging from 50% to 100% in increments of 10% were derived and tabulated in Table 4. The DCPFN would make an excellent laboratory developmental device since it affords the versatility of being able to drive a wide range of loads with a single pulse forming network.

CONCLUSION

We have shown that constant power, long output pulses can be generated for a wide range of loads from a DCPFN. We have also presented the normalized coefficients for a Type C DCPFN for efficiencies ranging from 50% to 100%, which may be converted to the other types of PFNs via network transformations [3].

Table 1
Pulse Transformer Parameters

Primary Winding		
Inner Radius	26.58	cm
Thickness	0.3175	cm
Width	105.0	cm
Inductance	219.2	nH
Secondary Winding		
Number of Turns	10	turns
Inner Radius	25.00	cm
Thickness	0.0508	cm
Pitch	0.1575	cm
Width	100.0	cm
Inductance	20.76	μH
Coupling		
Coefficient	0.9641	
Mutual Inductance	2.056	μH

Table 2
Possible Transformer-Load Combinations

Turns Ratio	Secondary Inductance	Coupling Coefficient	Load Resistance
1:10	20.76 μH	0.9641	10.0 Ω
1:9	16.76 μH	0.9663	8.1 Ω
1:8	13.20 μH	0.9685	6.4 Ω
1:7	10.08 μH	0.9703	4.9 Ω
1:6	7.38 μH	0.9726	3.6 Ω
1:5	5.11 μH	0.9748	2.5 Ω
1:4	3.26 μH	0.9771	1.6 Ω

Table 3
100 GW/250 KJ DCPFN Parameters (+/- 100 KV CHARGE)

Component	Scaled Values
C1	16.23 μF
L1	39.00 nH
C2	1.53 μH
L2	103.80 nH
C3	1.80 μF
L3	39.00 nH
C4	380.00 nF
L4	103.80 nH
C5	650.00 nF
L5	39.00 nH
C6	170.00 nF
L6	103.80 nH
C7	332.50 nF
L7	39.00 nH
C8	95.00 nF
L8	103.80 nF
C9	200.00 nF
L9	39.00 nH
C10	60.00 nF
L10	103.80 nH

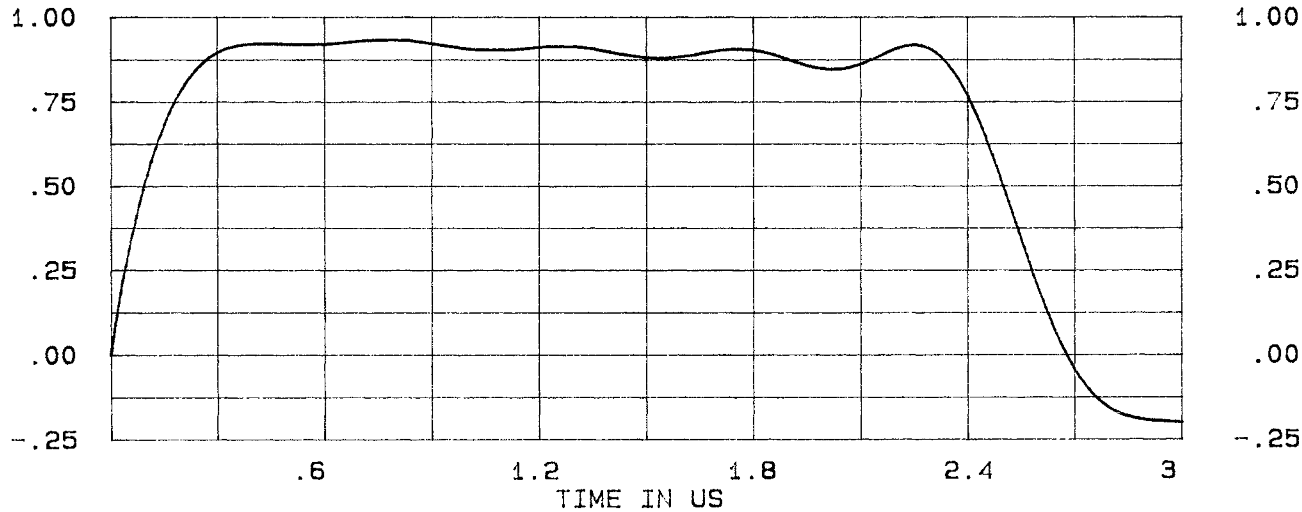

Figure 3. 100 GW, 0.25 MJ Pulse

Table 4
Normalized Droop Compensated Pulse Forming Network Coefficients

	Efficiency Values					
Components	50%	60%	70%	80%	90%	100%
C1	810.6E-3	675.5E-3	579.0E-3	506.6E-3	450.3E-3	405.3E-3
L1	125.0E-3	150.0E-3	175.0E-3	200.0E-3	225.0E-3	250.0E-3
C2	101.3E-3	675.5E-4	434.2E-4	253.3E-4	112.6E-4	NA
L2	250.0E-3	375.0E-3	583.3E-3	100.0E-2	225.0E-2	NA
C3	900.6E-4	750.5E-4	643.3E-4	562.9E-4	500.4E-4	450.3E-4
L3	125.0E-3	150.0E-3	175.0E-3	200.0E-3	225.0E-3	250.0E-3
C4	253.3E-4	168.9E-4	108.6E-4	633.3E-5	281.4E-5	NA
L4	250.0E-3	375.0E-3	583.3E-3	100.0E-2	225.0E-2	NA
C5	324.2E-4	270.2E-4	231.6E-4	202.6E-4	180.1E-4	162.1E-4
L5	125.0E-3	150.0E-3	175.0E-3	200.0E-3	225.0E-3	250.0E-3
C6	112.6E-4	750.5E-5	482.5E-5	281.4E-5	125.1E-5	NA
L6	250.0E-3	375.0E-3	583.3E-3	100.0E-2	225.0E-2	NA
C7	165.4E-4	137.9E-4	118.2E-4	103.4E-4	919.0E-5	827.1E-5
L7	125.0E-3	150.0E-3	175.0E-3	200.0E-3	225.0E-3	250.0E-3
C8	633.3E-5	422.2E-5	271.4E-5	158.3E-5	704.0E-6	NA
L8	250.0E-3	375.0E-3	583.3E-3	100.0E-2	225.0E-2	NA

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